Research on the Evaluation Index System for the Screening and Decision-making of Optical Current Transducer

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Abstract: As the Optical Current Transducer (OCT) is gradually and widely used in power systems, how to scientifically and accurately select OCT products with superior performance, high quality and low price plays an important prerequisite role in reducing maintenance costs, realizing the stable operation of the power system and improving economic benefits. Based on the characteristics of Optical Current Transducer, this thesis selects four index factors of functional stability, maintainability, price and electronic component quality, simultaneously using the Analytic Hierarchy Process(AHP) to analyze and evaluate each index factor. Finally, in the overall sorting screening stage, according to the principle of maximum membership degree, the element with the largest total sorting weight value is selected to be the optimal product decision plan.

Keywords: Optical current transducer; Analytic hierarchy process; Membership degree

1. Introduction

Compared with traditional current transducer, Optical Current Transducer (OCT) has the advantages of simple structure, light weight, being easy for installation, wide frequency response range, and strong anti-electromagnetic interference ability. In recent years, OCT has been gradually and widely used in power systems with its significant comparative advantages. However, due to the distinction of different manufacturers in the cost input and precision of production process, the quality and the performance value of OCT products on the market is uneven and unbalanced, which results in certain challenges to consumers who are trapped in purchasing decision. Therefore, it is of important reference value to establish a scientific, reasonable and complete OCT screening and decision-making evaluation index system to comprehensively screen and evaluate for OCT consumers towards its suppliers.

2. Analysis of Factors Affecting the Selection of Optical Current Transducer

Based on the characteristics of optical current transducer, and taking into account factors such as after-sales service and product process innovation in the corporate balanced scorecard strategy [1], this article summarizes the four main index factors affecting the selection of optical current transducer:

2.1. Functional stability

Since the stability of optical current transducer is easily affected by temperature, birefringence and current harmonics, its functional stability is an important factor which would have an effect on product selection.

2.2. Maintainability

The maintainability of the equipment affects the investment in maintenance costs and the convenience of replacement of essential spare parts for consumers.

2.3. Price

The purchasing cost advantage of the consumer reflects on the reasonable lower price of the manufacturer's products.

2.4. Quality of electronic components

The quality of OCT's raw materials and electronic components directly affects the quality and service life of the finished product.

3. Establishment of the Evaluation Index System for the Screening and Decision-making of Optical Current Transducer

The Analytic Hierarchy Process (AHP) was proposed in the early 1970s by Mr.T.L.Saaty, a famous American professor in the field of operations research [2]. When studying the topic of power distribution, he used the evaluation method of digital quantitative analysis for the first time to break the long-standing situation where only words could be used to qualitatively evaluate factors. This method uses consistency criteria to test the accuracy of risk assessment, and the quantitative results produced can provide decision-makers with a clear and reliable basis for decision-making. This thesis uses the Analytic Hierarchy Process to solve the problem of blind spots in the procurement and selection of optical current transducer, and optimizes the product procurement plan by constructing an OCT screening and evaluation index system. The establishment of the indicator system includes the following steps.

3.1. Establish a hierarchical structure

The hierarchical structure of the research object--optical current transducer in this thesis is composed of the target layer, the criterion layer and the scheme layer. The target layer is the selection of the optimal OCT; the criterion layer is the four index factors that affect the selection of the optical current transducer; the scheme layer is composed of alternative scheme elements.

3.2. Construct the judgment matrix

According to the judgment matrix scale scores 1-9, the expert questionnaire method is used to compare the factors of the criterion layer and the scheme layer, and the importance of the comparison is scored to obtain the expert judgment matrix of each layer.

Table 1. The scale of the judgment matrix and its meaning [3]

Scale	Meaning
1	Indicates that two factors are of equal importance when compared to each other
3	Indicates that the former factor is slightly more important than the latter one when compared to each other
5	Indicates that the former factor is obviously more important than the latter one when compared to each other
7	Indicates that the former factor is strongly more important than the latter one when compared to each other
9	Indicates that the former factor is extremely important than the latter one when compared to each other
2,4,6,8	Indicates the middle value between the above two adjacent scales
Reciprocal	Ratio of factor i to j is recorded as a_{ij} , while ratio of factor j to i is recorded as $a_{ji}=1/a_{ij}$

3.3. Calculate the single sorting weight vector and test the consistency

3.3.1. Firstly, test the consistency of the judgment matrix:

Calculate the maximum eigenvalue, λ_{max} , of the judgment matrix

$$\lambda_{max}=\frac{1}{n}\sum_{i=1}^{n}\frac{(AW)_i}{W_i} \quad (1)$$

Calculate the consistency index, CI, of the judgment matrix.

$$CI=\frac{\text{Maximum Eigenvalue- Matrix Order}}{\text{Matrix Order-1}}=\frac{\lambda_{max}-n}{n-1} \quad (2)$$

Calculate the consistency index rate, CR, of the judgment matrix, where RI could be referred to the random consistency index table 2.2.

$$CR=\frac{CI}{RI} \quad (3)$$

If CR<0.1, then the matrix A meets the consistency requirement; if CR ≧0.1, then the
the consistency requirement.

Table 2. Random consistency index RI reference table

Matrix Order	1	2	3	4	5	6
RI	0	0	0.52	0.89	1.12	1.26
Matrix Order	7	8	9	10	11	12
RI	1.36	1.41	1.46	1.49	1.52	1.54

3.3.2. Use the geometric average method to solve the eigenvector of the judgment matrix:

Multiply the elements of each row separately of the matrix, and record the product of each row as $Multiply_i$.

$$Multiply_i=\prod_{i=1}^{n}a_{ij}\left(j=1,2,3\cdots,m\right) \quad (4)$$

(n and m respectively represents the number of rows and columns of the matrix, and in this research, always keeping m=n, that means, n is also the Matrix Order)

Figure out the n^th root of M_i to get $\overline{W_i}$, and then form a vector, $\overline{W}$.

$$\overline{W_i}=\sqrt[n]{M_i} \quad (5)$$

$$\overline{W}=\left(\overline{W_1},\overline{W_2},\cdots,\overline{W_n}\right) \quad (6)$$

Normalize the vector $\overline{W}^T$ to obtain the Eigenvector, W_i , of the judgment matrix.

$$W_i=\frac{\overline{W_i}}{\sum_{j=1}^{n}\overline{W_j}} \quad (7)$$

$$W=\left(W_1,W_2,\cdots,W_n\right)^T \quad (8)$$

3.4. Overall sorting screening

The eigenvectors of the scheme layer matrix Bi under each element of the criterion layer A are formed into a matrix WB. The total sorting weight value is calculated according to the formula, and the total sorting consistency test shall be simultaneously performed. Finally, based on the principle of maximum membership, the optimal plan for the overall goal could be selected.

4. Case Verification

The Y power engineering project team plans to purchase a group of optical current transducers from one of the three manufacturers such as Guilin SH, Ningbo KN, and Jinan QP. Y team mainly attaches importance to the four index factors such as functional stability, maintainability, price and electronic components quality of OCT. By implementing the questionnaire survey towards several experts of the Y team, the relative importance scores between each two index factors shall be obtained to make a comprehensive evaluation.

4.1. Establish an evaluation index system for the screening and decision-making of optical current transducer of Y project team

The target layer of the evaluation index system is to select the optimal current transducer; the criterion layer consists of the four index factors of functional stability, maintainability, price and electronic component quality; the scheme layer is Guilin SH Manufacturer, Ningbo KN Manufacturer and Jinan QP Manufacturer.

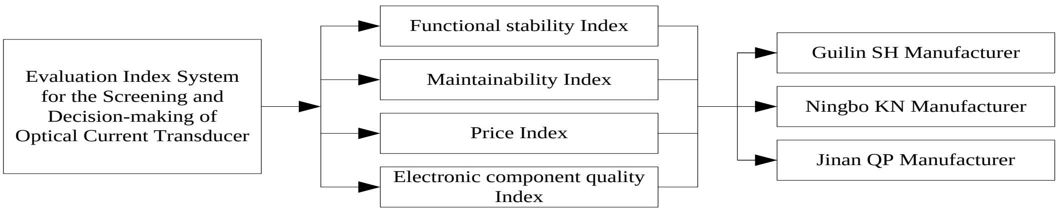

Figure 1. Evaluation index system for the screening and decision-making of optical current transducer

4.2. Construct the OCT judgment matrix and calculate the single sorting weight vector

4.2.1. Construct the judgment matrix and calculate the weight vector of OCT criterion layer

According to table 3, use the expert questionnaire survey method to score the four factors of the criterion layer, and the score is based on the importance of the comparison between the two, so as to obtain the expert judgment matrix of this layer.

Table 3. Comparison judgment matrix A of criterion layer

	Functional stability	Maintainability	Price	Electronic component quality
Functional stability	1	3	5	6
Maintainability	1/3	1	4	5
Price	1/5	1/4	1	3
Electronic component quality	1/6	1/5	1/3	1

$$A=\begin{bmatrix} 1 & 3 & 5 & 6 \\ 0.333 & 1 & 4 & 5 \\ 0.2 & 0.25 & 1 & 3 \\ 0.167 & 0.2 & 0.333 & 1 \end{bmatrix} \tag{9}$$

Perform the consistency test

Calculate the maximum eigenvalue of the matrix A

$$\begin{cases} \lambda_{\max}=4.204 \\ CI=\dfrac{\lambda_{\max}-n}{n-1}=\dfrac{4.204-4}{4-1}=0.068 \\ CR=\dfrac{CI}{RI}=\dfrac{0.068}{0.89}=0.076 \end{cases} \tag{10}$$

Table 4. Summary of eigenvector of criterion layer

	Functional stability	Maintainability	Price	Electronic component quality	Product of elements in each row M_i	Mi's Fourth root, $\overline{W_i}$	Normalized Eigenvector, W_i
Functional stability	1	3	5	6	90	3.0801	0.547
Maintainability	0.333	1	4	5	6.66	1.6065	0.285
Price	0.2	0.25	1	3	0.15	0.6223	0.110
Electronic component quality	0.167	0.2	0.333	1	0.0111	0.3247	0.058

Since CR<0.1, the Criterion layer matrix A meets the consistency test requirement.

According to formulas (4)-(8), calculate the eigenvector, W_i of the Criterion layer judgment matrix A.

$$\begin{cases} Multiply_1 = \prod_{i=1} a_{1j}(j=1,2,3,4) = 1\times3\times5\times6 = 90 \\ Multiply_2 = \prod_{i=2} a_{2j}(j=1,2,3,4) = 0.333\times1\times4\times5 = 6.66 \\ Multiply_3 = \prod_{i=3} a_{3j}(j=1,2,3,4) = 0.2\times0.25\times1\times3 = 0.15 \\ Multiply_4 = \prod_{i=4} a_{4j}(j=1,2,3,4) = 0.167\times0.2\times0.333\times1 = 0.0111 \end{cases} \quad (11)$$

$$\begin{cases} \overline{W_1} = \sqrt[4]{M_1} = \sqrt[4]{90} = 3.0801 \\ \overline{W_2} = \sqrt[4]{M_2} = \sqrt[4]{6.66} = 1.6065 \\ \overline{W_3} = \sqrt[4]{M_3} = \sqrt[4]{0.15} = 0.6223 \\ \overline{W_4} = \sqrt[4]{M_4} = \sqrt[4]{0.0111} = 0.3247 \end{cases} \quad (12)$$

$$\begin{cases} W_1 = \frac{\overline{W_1}}{\sum_{j=1}^{n}\overline{W_j}} = \frac{3.0801}{3.0801+1.6065+0.6223+0.3247} = 0.547 \\ W_2 = \frac{\overline{W_2}}{\sum_{j=1}^{n}\overline{W_j}} = \frac{1.6065}{3.0801+1.6065+0.6223+0.3247} = 0.285 \\ W_3 = \frac{\overline{W_3}}{\sum_{j=1}^{n}\overline{W_j}} = \frac{0.6223}{3.0801+1.6065+0.6223+0.3247} = 0.110 \\ W_4 = \frac{\overline{W_4}}{\sum_{j=1}^{n}\overline{W_j}} = \frac{0.3247}{3.0801+1.6065+0.6223+0.3247} = 0.058 \end{cases} \quad (13)$$

4.2.2. Construct the judgment matrix B1 and calculate the weight vector of scheme layer under the functional stability

Construct the matrix B1

Table 5. Functional stability matrix B1

B1	SH	KN	QP
SH	1	1/2	1/5
KN	2	1	1/3
QP	5	3	1

$$B1 = \begin{bmatrix} 1 & 0.5 & 0.2 \\ 2 & 1 & 0.333 \\ 5 & 3 & 1 \end{bmatrix} \quad (14)$$

Perform the consistency test

Calculate the maximum eigenvalue of the matrix B1

$$\lambda_{\max} = 3.004 \quad (15)$$

$$\begin{cases} CI = \frac{\lambda_{\max} - n}{n-1} = \frac{3.004-3}{3-1} = 0.002 \\ CR = \frac{CI}{RI} = \frac{0.002}{0.52} = 0.0038 \end{cases} \quad (16)$$

Since CR<0.1, the Functional stability matrix B1 meets the consistency test requirement.

According to formulas (4)-(8), calculate the eigenvector, W_i of the Functional stability matrix B1

$$\begin{cases} Multiply_1 = \prod_{i=1} a_{1j}(j=1,2,3) = 1\times0.5\times0.2 = 0.1 \\ Multiply_2 = \prod_{i=2} a_{2j}(j=1,2,3) = 2\times1\times0.333 = 0.666 \\ Multiply_3 = \prod_{i=3} a_{3j}(j=1,2,3) = 5\times3\times1 = 15 \end{cases} \quad (17)$$

$$\begin{aligned} \overline{W_1} &= \sqrt[3]{M_1} = \sqrt[3]{0.1} = 0.4642 \\ \overline{W_2} &= \sqrt[3]{M_2} = \sqrt[3]{0.666} = 0.8733 \\ \overline{W_3} &= \sqrt[3]{M_3} = \sqrt[3]{15} = 2.4662 \end{aligned} \quad (18)$$

$$\begin{cases} W_1 = \frac{\overline{W_1}}{\sum_{j=1}^{n}\overline{W_j}} = \frac{0.4642}{0.4642+0.8733+2.4622} = 0.122 \\ W_2 = \frac{\overline{W_2}}{\sum_{j=1}^{n}\overline{W_j}} = \frac{0.8733}{0.4642+0.8733+2.4662} = 0.230 \\ W_3 = \frac{\overline{W_3}}{\sum_{j=1}^{n}\overline{W_j}} = \frac{2.4662}{0.4642+0.8733+2.4662} = 0.648 \end{cases} \quad (19)$$

Table 6. Summary of eigenvector of scheme layer under the functional stability

B1	SH	KN	QP	Product of elements in each row, M_i	Mi's Cubic root, $\overline{W_i}$	Normalized Eigenvector, W_i
SH	1	0.5	0.2	0.1	0.4642	0.122
KN	2	1	0.333	0.666	0.8733	0.230
QP	5	3	1	15	2.4662	0.648

As seen from the table 6, without considering other factors, only in terms of the functional stability of the optical current transducer, since $W_3>W_2>W_1$, Jinan QP Manufacturer's products have the best functional stability.

4.2.3. Construct the judgment matrix B2 and calculate the weight vector of scheme layer under the maintainability

Construct the matrix B2

Table 7. Maintainability matrix B2

B2	SH	KN	QP
SH	1	7	4
KN	1/7	1	1/2
QP	1/4	2	1

$$B2 = \begin{bmatrix} 1 & 7 & 4 \\ 0.143 & 1 & 0.5 \\ 0.25 & 2 & 1 \end{bmatrix} \quad (20)$$

Perform the consistency test

Calculate the maximum eigenvalue of the matrix B2

$$\lambda_{\max} = 3.002 \quad (21)$$

$$\begin{cases} CI = \dfrac{\lambda_{\max} - n}{n-1} = \dfrac{3.002 - 3}{3-1} = 0.001 \\ CR = \dfrac{CI}{RI} = \dfrac{0.001}{0.52} = 0.0019 \end{cases} \quad (22)$$

Since CR<0.1, the Maintainability matrix B2 meets the consistency test requirement.

According to formulas (4)-(8), calculate the eigenvector, W_i of the Maintainability matrix B2

Table 8. Summary of eigenvector of scheme layer under the maintainability

B2	SH	KN	QP	Product of elements in each row, M_i	Mi's Cubic root, $\overline{W}_i$	Normalized Eigenvector, W_i
SH	1	7	4	28	3.0366	0.715
KN	0.143	1	0.5	0.0715	0.4151	0.098
QP	0.25	2	1	0.5	0.7937	0.187

As seen from the table 8, without considering other factors, only in terms of the maintainability of optical current transducers, since $W_1>W_3>W_2$, the products of Guilin SH Manufacturer have the strongest maintainability.

4.2.4. Construct the judgment matrix B3 and calculate the weight vector of scheme layer under the price

$$B3 = \begin{bmatrix} 1 & 0.222 & 0.4 \\ 4.5 & 1 & 3 \\ 2.5 & 0.333 & 1 \end{bmatrix} \quad (23)$$

Perform the consistency test

Calculate the maximum eigenvalue of the matrix B3

$$\lambda_{\max} = 3.029 \quad (24)$$

$$\begin{cases} CI = \dfrac{\lambda_{\max} - n}{n-1} = \dfrac{3.029 - 3}{3-1} = 0.0145 \\ CR = \dfrac{CI}{RI} = \dfrac{0.0145}{0.52} = 0.0279 \end{cases} \quad (25)$$

Since CR<0.1, the Price matrix B3 meets the consistency test requirement.

According to formulas (4)-(8), calculate the eigenvector, W_i of the Price matrix B3

Table 9. Summary of eigenvector of scheme layer under the price

B3	SH	KN	QP	Product of elements in each row, M_i	Mi's Cubic root, $\overline{W}_i$	Normalized Eigenvector, W_i
SH	1	0.222	0.4	0.0888	0.4461	0.118
KN	4.5	1	3	13.5	2.3811	0.632
QP	2.5	0.333	1	0.8325	0.9407	0.250

As seen from the table 9, without considering other factors, only in terms of the price of optical current transducer, since $W_2>W_3>W_1$, Ningbo KN Manufacturer's products are the most affordable.

4.2.5. Construct the judgment matrix B4 and calculate the weight vector of scheme layer under the electronic component quality

Construct the matrix B4

Table 10. Electronic component quality matrix B4

B4	SH	KN	QP
SH	1	3/2	3/7
KN	2/3	1	2/7
QP	7/3	7/2	1

$$B4 = \begin{bmatrix} 1 & 1.5 & 0.429 \\ 0.667 & 1 & 0.286 \\ 2.333 & 3.5 & 1 \end{bmatrix} \quad (26)$$

Perform the consistency test

Calculate the maximum eigenvalue of the matrix B4

$$\lambda_{\max} = 3.0 \quad (27)$$

$$\begin{cases} CI = \dfrac{\lambda_{\max} - n}{n-1} = \dfrac{3.0 - 3}{3-1} = 0 \\ CR = \dfrac{CI}{RI} = \dfrac{0}{0.52} = 0 \end{cases} \quad (28)$$

Since CR<0.1, the Electronic component quality matrix B4 meets the consistency test requirement.

According to formulas (4)-(8), calculate the eigenvector, W_i of the Electronic component quality matrix B4.

Table 11. Summary of eigenvector of scheme layer under the electronic component quality

B4	SH	KN	QP	Product of elements in each row, M_i	Mi's Cubic root, $\overline{W}_i$	Normalized Eigenvector, W_i

SH	1	1.5	0.429	0.6435	0.8633	0.250
KN	0.667	1	0.286	0.1908	0.5757	0.167
QP	2.333	3.5	1	8.1655	2.0137	0.583

As seen from the table 11, without considering other factors, only in terms of the quality of the electronic components of the optical current transducer, since $W_3>W_1>W_2$, the product quality of Jinan QP Manufacturer is the best.

4.3. Overall sorting optimization

4.3.1. Calculate the total sorting weight value W_T

Organize the eigenvectors from the functional stability matrix B1, maintainability matrix B2, price matrix B3 and electronic component quality matrix B4 to form the matrix W_B; Organize the eigenvectors from criterion layer to form the matrix W_A; Calculate the total sorting weight W_T according to the formula as shown below.

$$W_B = \begin{bmatrix} W_{B1} & W_{B2} & W_{B3} & W_{B4} \end{bmatrix} = \begin{bmatrix} 0.122 & 0.715 & 0.118 & 0.250 \\ 0.230 & 0.098 & 0.632 & 0.167 \\ 0.648 & 0.187 & 0.250 & 0.583 \end{bmatrix} \quad (29)$$

$$W_A = \begin{bmatrix} 0.547 \\ 0.285 \\ 0.110 \\ 0.058 \end{bmatrix} \quad (30)$$

$$W_T = \begin{bmatrix} W_{B1} & W_{B2} & W_{B3} & W_{B4} \end{bmatrix} \times [W_A] = \begin{bmatrix} 0.122 & 0.715 & 0.118 & 0.250 \\ 0.230 & 0.098 & 0.632 & 0.167 \\ 0.648 & 0.187 & 0.250 & 0.583 \end{bmatrix} \times \begin{bmatrix} 0.547 \\ 0.285 \\ 0.110 \\ 0.058 \end{bmatrix} = \begin{bmatrix} 0.298 \\ 0.233 \\ 0.469 \end{bmatrix} \quad (31)$$

Table 12. The total sorting weight value table of optical current transducer

	Functional stability Matrix WB_1	**Maintainability Matrix WB_2**	**Price Matrix WB_3**	**Electronic component quality matrix WB_4**	**Total sorting weight value W_T**
SH Eigenvector	0.122	0.715	0.118	0.250	0.298
KN Eigenvector	0.230	0.098	0.632	0.167	0.233
QP Eigenvector	0.648	0.187	0.250	0.583	0.469

4.3.2. Perform the consistency test for the total sorting index, CI_T

Given that the eigenvector matrix W_A of the criterion layer, and the matrix CI_B is composed of the consistency indexes from the matrices B1, B2, B3 and B4, therefore:

$$CI_B = \begin{bmatrix} CI_{B1} & CI_{B2} & CI_{B3} & CI_{B4} \end{bmatrix} = \begin{bmatrix} 0.002 & 0.001 & 0.0145 & 0 \end{bmatrix} \quad (32)$$

$$CI_T = \begin{bmatrix} CI_{B1} & CI_{B2} & CI_{B3} & CI_{B4} \end{bmatrix} \times [W_A] = \begin{bmatrix} 0.002 & 0.001 & 0.0145 & 0 \end{bmatrix} \times \begin{bmatrix} 0.547 \\ 0.285 \\ 0.110 \\ 0.058 \end{bmatrix} = 0.0030 \quad (33)$$

Since n=3, the random consistency index RI = 0.52, so the total sorting index rate CR_T equals to:

$$CR_T = \frac{CI_T}{RI} = \frac{0.0030}{0.52} = 0.0058 \quad (34)$$

Since $CR_T<0.1$, the total sorting index meets the consistency test requirements. As seen from the table 3.11, the total sorting weight value of each manufacturer is $WT_{QP}>WT_{SH}>WT_{KN}=0.469>0.298>0.233$. According to the principle of maximum degree of membership, after the comprehensive evaluation of functional stability, maintainability, price and electronic component quality index factors, the optical current transformer from Jinan QP manufacturer has the best comprehensive cost performance.

5. Conclusion

This article analyzes and evaluates various index factors affecting the optical current transducer in detail by using the Analytic Hierarchy Process. By constructing an optical current transformer screening & decision-making evaluation index system, the total sorting weight value of OCT is scientifically and accurately calculated and the element with the largest weight value is quantitatively displayed, forming the optimal decision-making plan for the product. This decision-making method not only provides a basis for the consumer to reasonably choose the OCT product with the highest comprehensive cost-effectiveness, but also has a significant effect on reducing cost and increasing efficiency.

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